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BROOKHAVEN NATIONAL LABORATORY

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to: Steven Bellavia

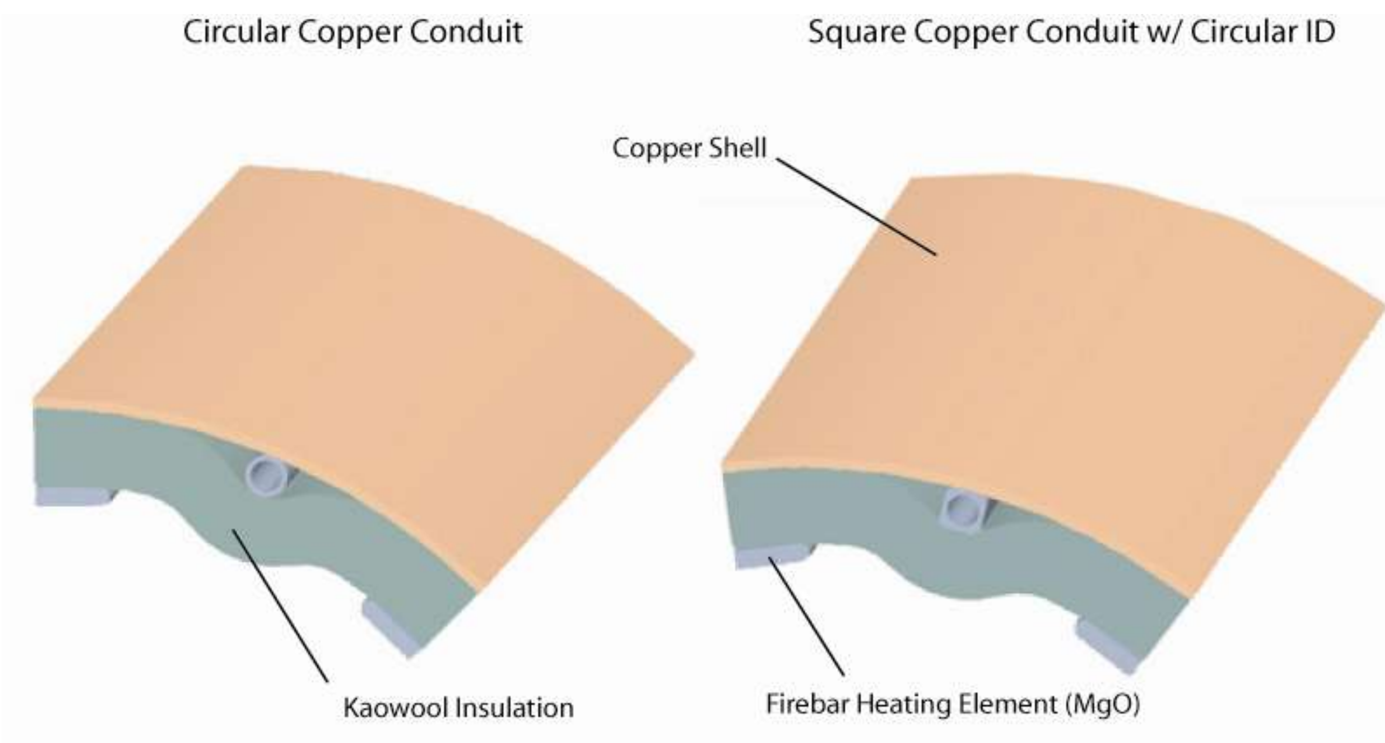
from: Gavin McIntyre

subject: EBIS Drift Tube Bake Out and Cooling

Discussion:

A thermal engineering analysis was performed on two models with a variation in copper conduit geometry that would contain the working fluid, water, for cooling the copper shell. Three magnitudes of weld/brazing lengths were analyzed concurrently to find the optimal cooling conditions.

Materials, Geometry and Loads:



The copper conduits had identical outer and internal diameters, 0.25” (6.35 mm) and 0.187” (4.75 mm) respectively, and run the entire length of the 12” models. An eighth symmetric model was selected and simulated using ANSYS Classic v.11.

The loads that were applied included convection, with water as the working fluid, applied to the internal areas of the tubing. The film coefficient was 8319.69 W/m^2-K and the bulk temperature was 298K, the corresponding hand calculations for the obtained film coefficient are located in Appendix A. Additionally a heat generation for the Firebar heating elements was applied to the appropriate volumes with a value of 7.59e6 W/m^3, which represents the full 100% duty cycle.

FEA Thermal Model:

Temperatures were coupled via nodes from volume to volume to simulate the conductive heat transfer from the heat sources and sinks through the various materials. The coupled temperatures along the copper conduits and copper shell were varied in length to simulate different weld lengths including: a full length weld, a 1” weld every 12”, and a 1” weld every 6”.

The initial comparison is between the circular and square conduits that are thermally coupled (welded) along the entire length of the 12” model. The images display the temperature contours in section from the copper conduit to the copper shell, *figure 1* is the circular pipe and *figure 2* is the square conduit.

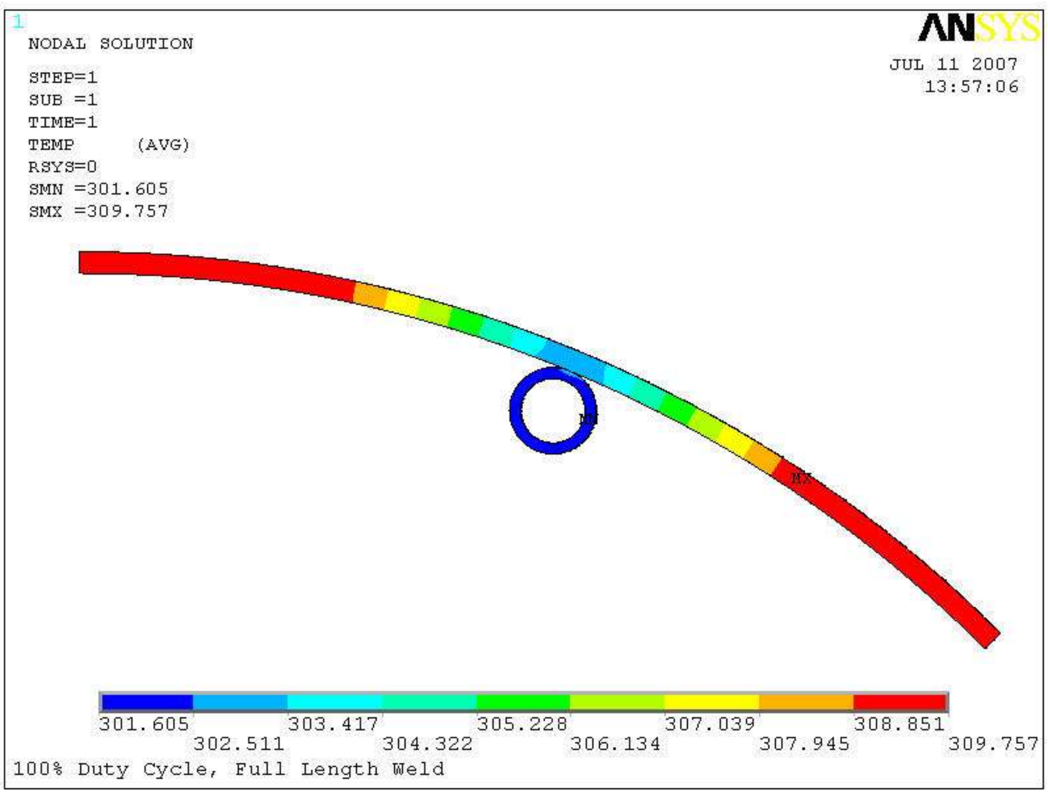


figure 1: full length weld with circular conduit

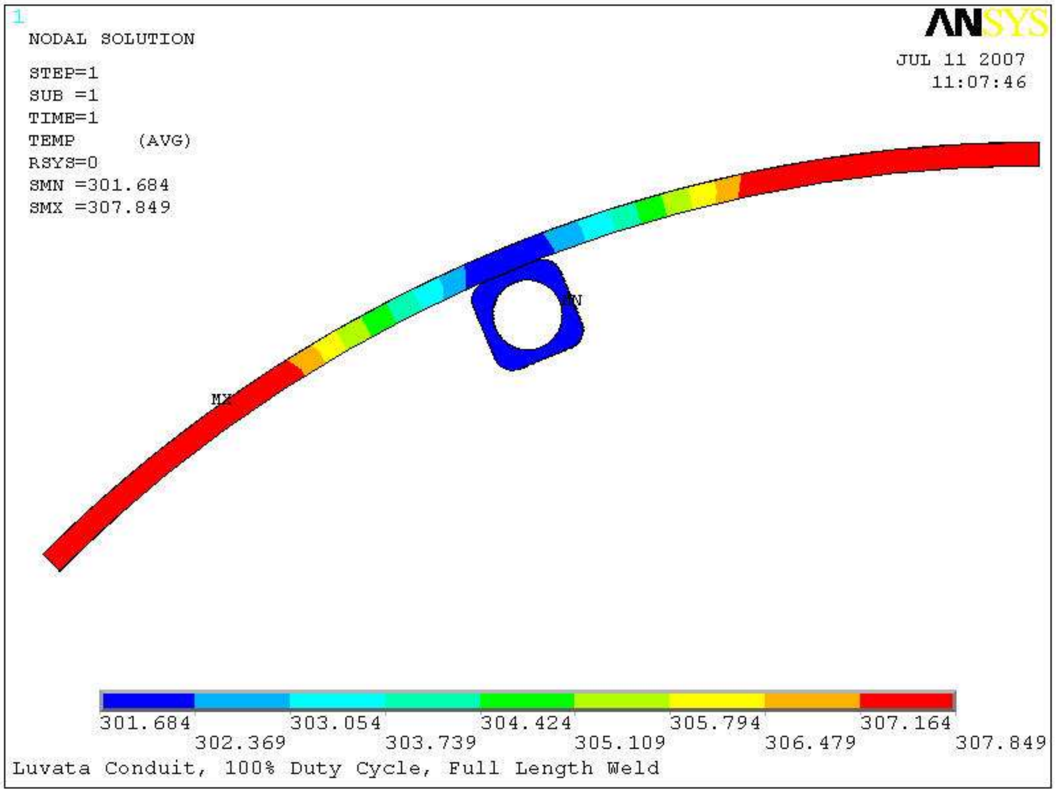


figure 2: full length weld with square Luvata conduit

The second comparison is between the circular and square conduits that are thermally coupled (welded) for 1", 0.5" on either side, of the 12" long model, *figure 3* is the circular pipe and *figure 4* is the square conduit.

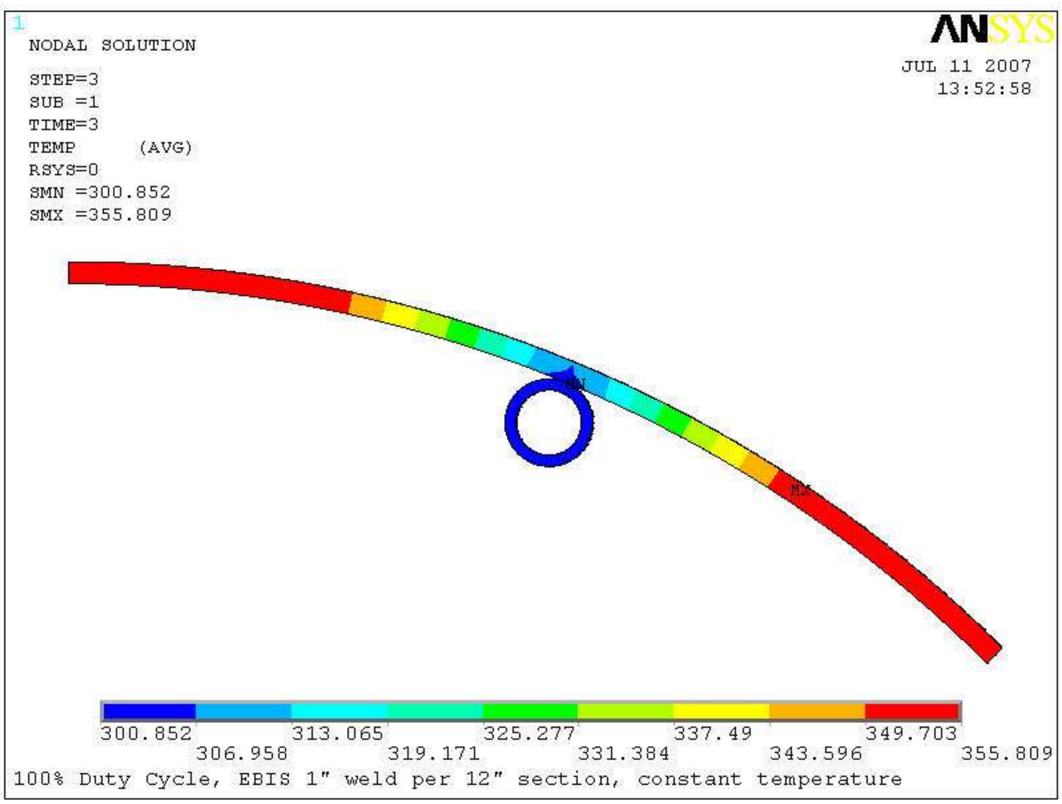


figure 3: 1" weld per 12" of length with circular conduit

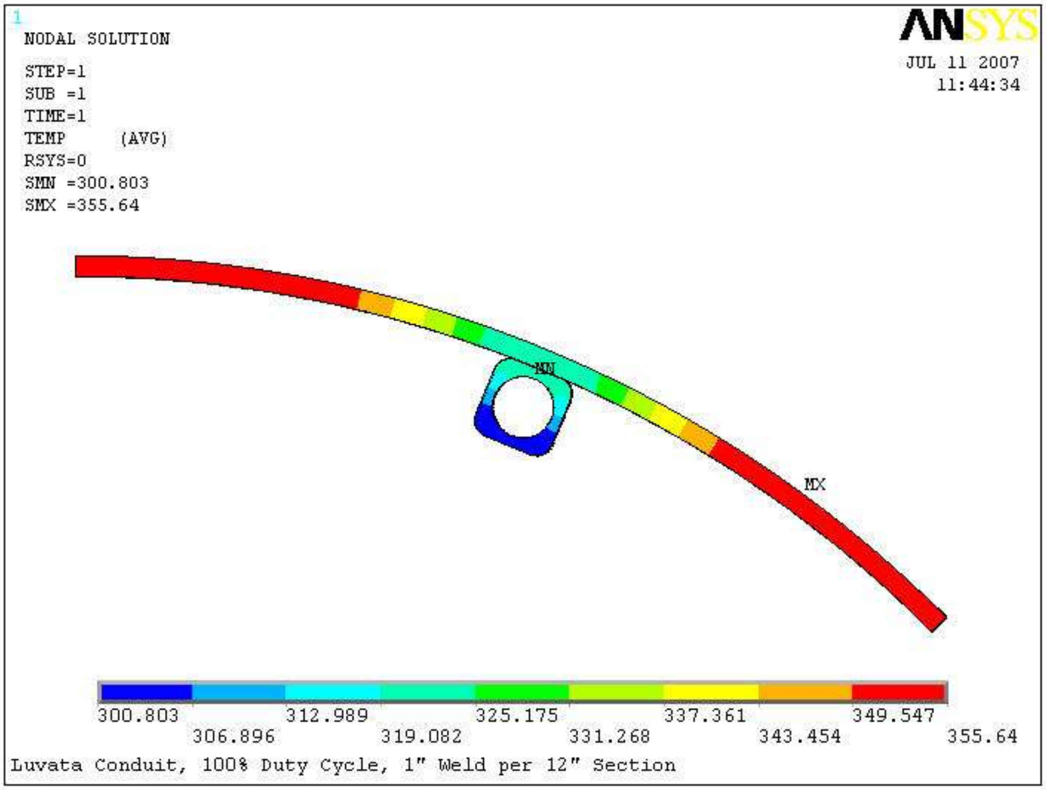


figure 4: 1" weld per 12" of length with square Luvata conduit

The third comparison is between the circular and square conduits that are thermally coupled (welded) to represent a 1" weld every 6". The couples are located at 0.5" on either side of the model and for an entire 1" in the center of the 12" long model, *figure 5* is the circular pipe and *figure 6* is the square conduit.

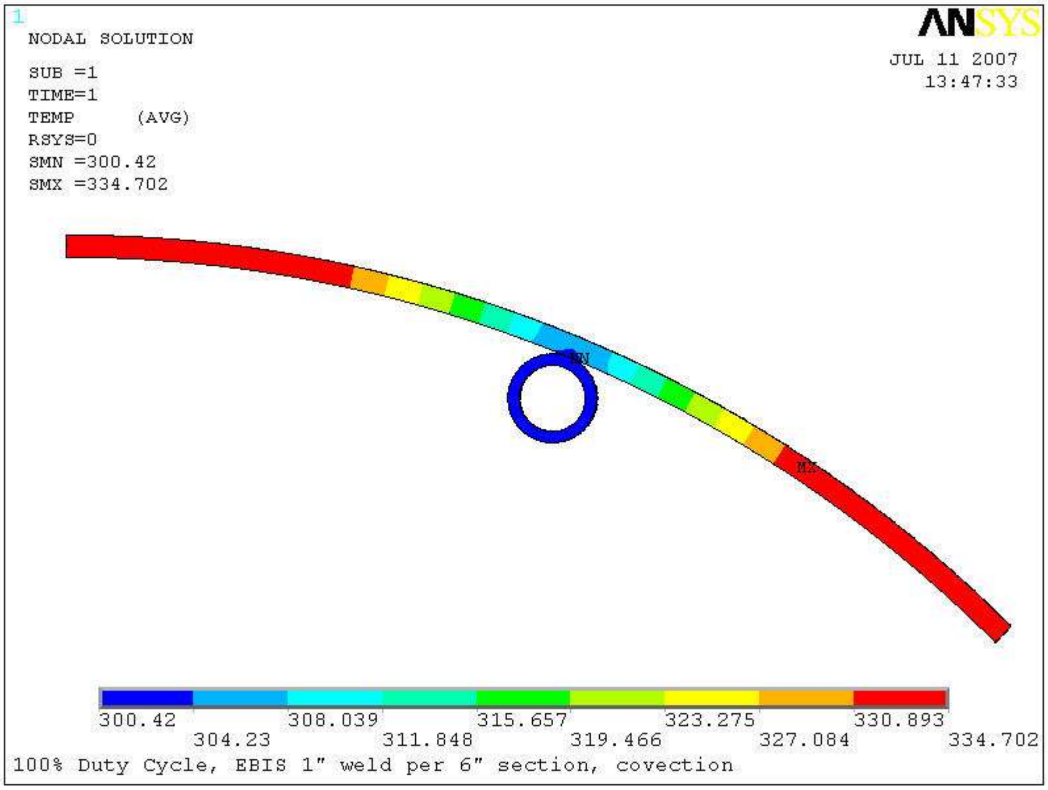


figure 5: 1" weld per 6" of length with circular conduit

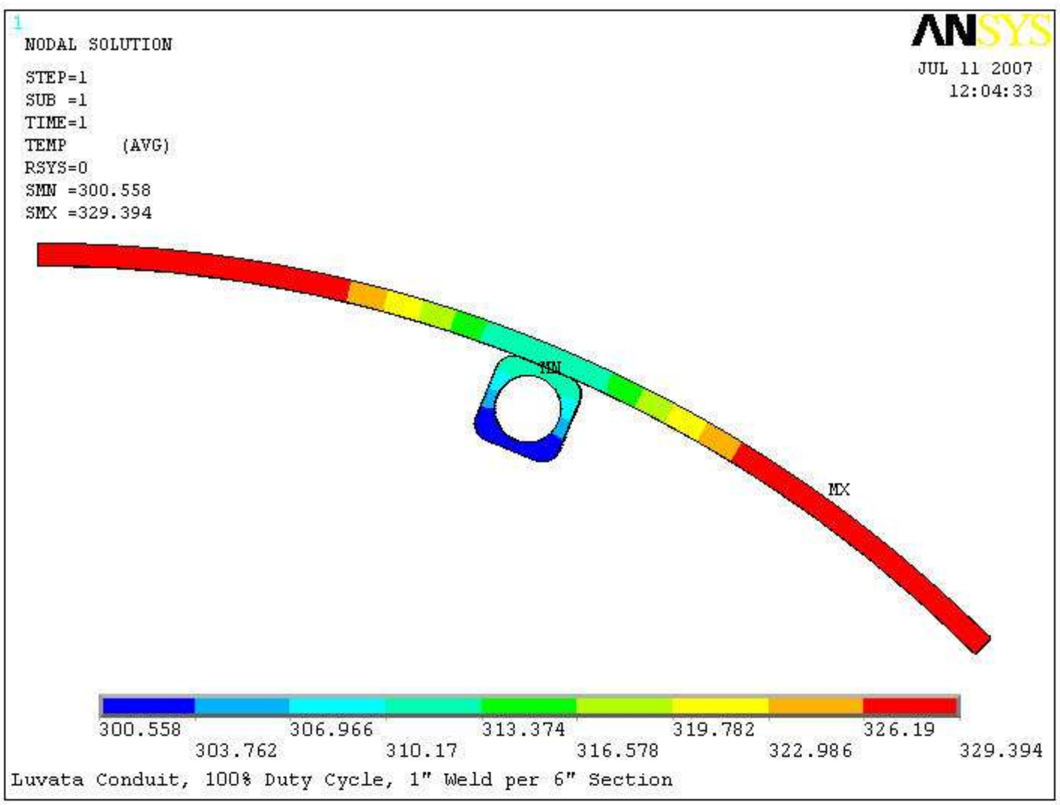


figure 6: 1" weld per 6" of length with square Luvata conduit

Results:

Weld/Braze Length	Circular Conduit Max. Temp	Square Conduit Max. Temp
Full length	309.76 K (37℃)	307.85 K (35℃)
1” / 6”	334.70 K (62℃)	329.39 K (56℃)
1” / 12”	355.80 K (83℃)	355.64 K (83℃)

Summary:

For optimal cooling conditions the Luvata square copper conduit should be implemented and brazed along the entire length of the material.

Appendix A: Hand Calculations for Film Coefficient

Convective Heat Transfer, working fluid Water

Using Engineering Equation Solver, evaluating at Room Temperature 298K, and atmospheric pressure 101.1 kPa

conductivity=k_(water, T=298K, , P=101 kPa) yields: $0.5948\left(\frac{W}{m \cdot K}\right)$

density=rho_(water, T=298K, P=101 kPa) yields: $997.1\left(\frac{kg}{m^3}\right)$

viscosity=mu_(water, T=298K, P=101 kPa) yields: $8.9e-4\left(\frac{kg}{m-s}\right)$

Pr=Prandtl(water, T=298K, P=101 kPa) yields: 6.263

$V = 2$ m/s

$D = 0.187" = 0.00475$ m

$$\mathrm{Re} = \left(\frac{\rho \cdot V \cdot D}{\mu}\right) = \left(\frac{997.1\left(\frac{kg}{m^3}\right) \cdot 2\left(\frac{m}{s}\right) \cdot 0.00475m}{8.9e-4\left(\frac{kg}{m-s}\right)}\right) = 10643.20$$

$$Nu = 0.023 \cdot \mathrm{Re}^{0.8} \cdot \mathrm{Pr}^{0.4} = 0.023 \cdot \left(10643.2^{0.8}\right) \cdot \left(6.263^{0.4}\right) = 79.81$$

$$Nu = \left(\frac{h \cdot D}{k}\right) \therefore h = \left(\frac{Nu \cdot k}{D}\right) = \left(\frac{79.81 \cdot 0.5948\left(\frac{W}{m-K}\right)}{0.00475m}\right) = 9994.08\left(\frac{W}{m^2-K}\right)$$